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Exploring the Underlying Components of Primary School Teachers' Pedagogical Content Knowledge for Technology Education

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In the study described in this article, primary school teachers' pedagogical content knowledge (PCK) of technology education was measured with a multiple choice test; the Teaching of Technology Test (TTT). The aim of the study was to explore the latent factor structure of PCK, which is considered to be a crucial and distinctive domain of teacher knowledge. As far as known, it is the first time that PCK is approached in this way. Many different components of PCK have been proposed in an attempt to define the concept, but these components have never been statistically confirmed. Three components were selected as the main knowledge components of PCK for technology education in primary schools: (1) Knowledge of pupils' concept of technology and knowledge of their pre and misconceptions related to technology; (2) Knowledge of the nature and purpose of technology education; (3) Knowledge of pedagogical approaches and teaching strategies for technology education. The results of this study gave useful insights into primary school teachers' PCK of technology education. It appeared that the theoretically predefined knowledge components could be indentified as latent factors. Furthermore, PCK could be characterized as a heterogeneous construct. That is, it consists of many intrinsic elements, which are difficult to unravel. Although measurement of PCK with a multiple-choice test has clear-cut advantages compared to qualitative methods and the results of the TTT are promising, further steps should be taken to reach satisfactory psychometric properties for practical application. This article provides ideas on how to (further) develop a multiple choice test to measure PCK.
Keywords: PCK; Technology Education; Primary School, Teacher Knowledge

INTRODUCTION

This study is focused on pedagogical content knowledge (PCK), which is considered to be a crucial and distinctive domain of teacher knowledge (Shulman 1987; Grossman 1990). The integrative domain of science and technology education in primary schools (K-6) in the Netherlands served as the research context. The measurement of primary school teachers' PCK was concentrated on technology (i.e., engineering) education exclusively, because most primary schools have implemented merely technology education rather than science and technology education in their curricula. Regarding technology education in primary schools, PCK is still fairly unexplored. An important finding in one of the few studies was that teachers' enhanced PCK in technology education was positively related to pupils' learning, motivation, and interest in technology (Jones and Moreland 2004).

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State of the literature

- Since the introduction of the construct in Anglo-Saxon literature by Lee Shulman in the late 1980s, PCK has become popular to investigate. Even though, the Continental European counterpart 'Fachdidaktik' has a much longer research tradition.
- Researchers agree on two essential components of PCK: (1) understanding of pupils' specific learning difficulties, and (2) knowledge of representations of the subject matter to overcome these difficulties.
- Most researchers, who investigated teachers' PCK, used multi method evaluations, a variety of techniques which typically includes structured, semi-structured or stimulated recall interviews, observations, and reflective journals.

Contribution of this paper to the literature

- In the present article, the results of a large scale (but still explorative) validation of a PCK test and, specifically, of the analysis of the latent factor structure underlying primary school teachers' PCK of technology education, are reported. As far as known, it is the first time that PCK is approached in this way.
- The knowledge components of technology PCK could theoretically and statistically be distinguished in three factors: (1) Knowledge of pupils' concept of technology and knowledge of their pre and misconceptions related to technology; (2) Knowledge of the nature and purpose of technology education; (3) Knowledge of pedagogical approaches and teaching strategies for technology education.
- However, the factor structure turned out to be obscured by many other intrinsic elements of PCK. Therefore, we conclude that PCK is a heterogeneous construct by nature. This implies that PCK consists of multiple intrinsic elements which can hardly be unraveled.

Since the beginning of this century, science and technology education in the Netherlands is encouraged by policy makers to increase the number of science and technology students and, thereby, advance the knowledge-based economy. The main goal of science and technology education for primary schools is described as 'to make pupils familiar with a rational approach of the natural world and its artifacts'. The pedagogical approaches that are recommended to use are inquiry-based and problem-based learning. This view on science and technology education is grounded on the theory of social constructivism, which involves a focus on learning, having pupils experience (hands-on) and explain (mind-on) themselves, cooperative learning, and different roles of the teacher (e.g., experts, coach, advisor). Moreover, a powerful learning environment with authentic and realistic problems or tasks that connect to pupils' prior experiences, knowledge, and interests is an important condition for science and technology education (Boersma et al. 2005). In the document of national standards for primary education in the Netherlands (Greven and Letschert 2006), seven standards for science and technology education are formulated, of which the two written below are specifically concerned with technology education:

(1) Pupils learn to find connections between the functioning, design, and use of materials of products in their own environment;

(2) Pupils learn to design, realize, and evaluate solutions for technical problems.

PCK makes teachers capable of transforming the subject matter into meaningful and effective learning activities (Shulman 1987; Van Driel et al. 1998). In order to find out how PCK develops and how it affects science and technology teaching and learning, research on teachers' PCK in science and technology education is needed. Solid research on PCK requires PCK to be conceptualized in a valid way. In turn, valid conceptualization is prerequisite to valid measurement of PCK. This study contributes to the conceptualization of PCK in technology education through measurement of primary school teachers' PCK with a multiple choice test and analysis of its latent factor structure. Our quantitative approach differs from other, more commonly used, approaches that can be characterized as in-depth and small-scale approaches, and addresses the concept from a different angle.

In a previously published article, the procedure of test construction and the results of a first (small scale) statistical exploration of the multiple choice test to measure technology PCK is reported (Rohaan et al. 2009). In the present article, the results of a large scale (but still explorative) validation of this test and, specifically, of the analysis of the latent factor structure underlying primary school teachers' PCK of technology education, are reported. As far as known, it is the first time that PCK is approached in this way. Many different components of PCK have been proposed in an attempt to define the concept (e.g., Shulman 1987; Van Driel et al. 1998; Grossman 1990; Carlsen 1999), but these components have never been statistically confirmed.

In the next section a short overview of research on the conceptualization and measurement of PCK in science education is given. Then, the method and results of this study are presented. In the final section, conclusions are formulated and the findings are critically discussed.

Pedagogical content knowledge

Since the introduction of the construct in Anglo-Saxon literature by Lee Shulman in the late 1980s, PCK has become popular to investigate. Even though, the Continental European counterpart 'Fachdidaktik' has a much longer research tradition. 'Fachdidaktik', however, is said to have a more normative character and to be less research-oriented than PCK (Kansanen 2009).

PCK is interpreted in many different ways, often to suit the research context (Mulholland and Wallace 2005). For example, some researchers include knowledge of the curriculum (e.g., Grossman 1990), while others exclude this knowledge component (e.g., Cochran et al. 1993). According to Van Driel et al. (1998) and Park and Oliver (2008), most researchers do agree on two essential components of PCK: (1) understanding of pupils' specific learning difficulties, and (2) knowledge of representations of the subject matter to overcome these difficulties. Furthermore, it is known that most researchers assume subject matter knowledge to be a prerequisite for the development of PCK (Van Driel et al. 1998).

With regard to the conceptualization of PCK in science education, Magnusson, Krajcik, and Borko (1999) presented two important issues. First, they stated that within each PCK component teachers need to have specific knowledge of each topic. In other words, effective teachers need to develop knowledge regarding every component of PCK and regarding all topics they teach. Second, they indicated that the components of PCK function as a whole. Consequently, a lack of coherence between the different components is problematic and a teacher's knowledge of one particular component may not be predictive for a teacher's teaching practice. Appleton (2008) theorized that the PCK development of primary school teachers may differ from secondary school teachers, because primary school teachers usually do not specialize in a specific domain. Therefore, they might not develop specific PCK for all the different subjects and topics they teach.

Another important characteristic of PCK in science education is the strong relationship with teachers' self-efficacy or self-confidence in teaching science. In a multiple case study, Park and Oliver (2008) revisited the concept of PCK and proposed teachers' self-efficacy, i.e., teachers' beliefs about their ability to enact effective teaching methods for specific teaching goals, to be an affective affiliate of PCK. This finding is in agreement with Appleton (2008), who assumed confidence in teaching science to be an important condition for the development of science PCK of primary school teachers. In other words, low levels of PCK are often related with low self-confidence (i.e., low self-efficacy).

Abell (2008) confirmed that PCK is still a useful construct twenty years after its introduction by Shulman. Besides, she expressed two important challenges for PCK researchers: (1) the relation of PCK to pupils' learning and (2) moving from descriptive to explanative research, in other words, shifting from small-scale to large-scale studies. This second challenge includes finding alternative ways to measure PCK.

Up to now, most researchers who investigated teachers' PCK (e.g., De Jong et al. 2005; Jones and Moreland 2004; Mulholland and Wallace 2005; Van Driel et al. 1998) used multi method evaluations, a variety of techniques which typically includes structured, semi-structured or stimulated recall interviews, observations, and reflective journals. Data from these sources are triangulated, usually resulting in a general profile of a teacher's PCK. This method requires teachers to be strongly involved in the research project, and is labor and time consuming. Because group sizes rarely exceed 10 and the results are very content, context, and teacher specific, generalization of the results is risky. Furthermore, psychometric quality indicators of multi method evaluations are hardly available, which makes comparison between different methods difficult.

Alternatively, a quantitative instrument (e.g., a multiple choice test) could be used to assess a teacher's PCK. A multiple choice test requires less teacher involvement, measures PCK in a time and labor efficient way, and makes it therefore possible to investigate large sample sizes. In addition, psychometric quality indicators of the measurement can be evaluated by strict and objective procedures.

PCK is constituted by what a teacher knows, what a teacher does, and the reasons for his actions (Baxter and Lederman 1999). A multiple choice test, however, is not suited to measure all these appearances of PCK, but is limited to 'what a teacher knows', the cognitive aspect of PCK. The reasoning ('the reasons for his actions') and behavioral ('what a teacher does') aspects are disregarded when using this method. On the other hand, PCK is not entirely expressed through behavior and teachers may only use a small portion of their PCK in observed situations and interviews will neither reveal all reasons for teaching behavior. Besides, it may be expected that measurement of 'cognitive' PCK with a multiple choice test is a good predictor for 'behavioral' PCK.

In the past, two promising initiatives to develop a multiple choice test to measure teachers' PCK were taken by Carlson (1990) and Kromrey and Renfrow (1991). In both studies, it was said that PCK test items should require the application of pedagogical knowledge to specific content areas, which means that the questioned teacher should have enough content knowledge of the topic in order to recognize the correct application of pedagogical strategies. Carlson (1990) as well as Kromrey and Renfrow (1991) reported

difficulties with writing good PCK items that are a balanced blend of content and pedagogical knowledge and have correct and convincing answer alternatives. Unfortunately, statistical analyses were absent and neither study was continued.

In order to design a multiple choice test to measure teachers' PCK for technology education in primary schools, the 'rational method' of test construction was followed (Oosterveld and Vorst 1996). This method could be classified as 'intuitive' and focuses on optimizing content validity. Rather than empirical data, judgments of experts are of particular importance for the specification and construction of the items. The rational method is specifically useful when the central construct is conceptualized insufficiently and empirical data are scarce.

Based on a review of scientific literature on PCK (Rohaan et al. 2010) and a discussion with experts in the field of technology education in primary schools, three components of PCK were selected as the main knowledge components of PCK for technology education in primary schools:

(1) Knowledge of pupils' concept of technology and knowledge of their pre and misconceptions related to technology;

(2) Knowledge of the nature and purpose of technology education;

(3) Knowledge of pedagogical approaches and teaching strategies for technology education.

Besides, PCK was defined by the experts, who were involved in the construction of the PCK test, as: "the knowledge a teacher needs in order to transform his or her content knowledge and pedagogical knowledge in a way that helps pupils to understand and learn the subject matter". This so-called 'construct analysis' laid the foundation for the construction of the Teaching of Technology Test (TTT).

The experts, who produced and judged the items, had a shared view on technology education, which was in line with the view presented in the introduction of this article, and agreed on the three basic knowledge components of PCK in primary technology education. Within each of these components sub-elements of PCK were formulated (e.g., 'know which misconceptions pupils often have and how to account for this in education' and 'know how to translate the nature and purposes of technology education in learning activities'). At least one sub-element was represented in each item and it was made sure that the test covered the entire construct of PCK, that is, contained a wide variety of sub-elements. Besides, the items involved two different phases of technology teaching (i.e., preparation and instruction/communication,) and varied on four technological topics (i.e., electricity, constructions, mechanic transmissions, and applied physics). An overview of the items and their characteristics are presented in Table 1. Figures 1 through 4 show four item examples of the TTT. A more detailed description of the test construction and the first small-scale administration and validation of the test was published eslewhere (see Rohaan, Taconis, & Jochems, 2009).

Table 1. Test items and their characteristics.

Item	PCK component*	Topic	Phase
1	1	Constructions	Preparation
2	1	No specific topic	Preparation
3	1	Applied physics	Preparation
4	1	Mechanical transmissions	Instruction/communication
5	3	Electricity	Preparation
6	3	No specific topic	No specific phase
7	3	Mechanical transmissions	Instruction/communication
8	3	No specific topic	No specific phase
9	2	Electricity	Preparation
10	2	Constructions	Preparation
11	3	Constructions	Preparation
12	1	Mechanical transmissions	Preparation
13	3	Mechanical transmissions	Instruction/communication
14	1	Electricity	Preparation
15	2	No specific topic	No specific phase
16	2	Constructions	Preparation
17	2	Applied physics	Preparation
18	1	No specific topic	No specific phase

**PCK components:*

1= knowledge of pupils' general concept and misconceptions related to technology.

2= knowledge of the nature and purpose of technology education.

3= knowledge of pedagogical approaches and teaching strategies for technology education.

METHODOLOGY

Instruments

For the measurement of primary school teachers' PCK of technology education, a slightly adapted version of the Teaching of Technology Test (TTT) was used (Rohaan et al. 2009). The TTT is a multiple choice test and contains 18 items with four answer alternatives each. The four alternatives were characterized a priori as to require 'high PCK', 'low PCK', exclusively pedagogical knowledge, or exclusively content knowledge ('no PCK').

With the intention to determine the construct validity of the TTT, teachers' content knowledge of technology was measured with the Cito technology test (Weerden et al. 2003). This test measures factual, or descriptive, knowledge and is originally designed to use with primary school pupils in the end of the sixth (last) grade, but turned out to be useful with primary school teachers as well. The Cito technology test is a multiple choice test that contains 48 items, which have three or four answer alternatives. Reliability (Cronbach's alpha) was found to be 0.79 for the present sample (n=361).

With the same intention, the Personal Science Teaching Efficacy Belief (PSTE) scale of the Science Teaching Efficacy Belief Instrument (STEBI) was used to measure self-efficacy in technology teaching. We adapted the STEBI from Bleicher (2004), which is a modification from the original by Enochs and Riggs (1990), translated it into Dutch and slightly revised it to fit the context of technology education. The scale contains 13 items with a 5 point Likert scale. Reliability (Cronbach's alpha) was found to be 0.91 for the present sample (n=354).

The instruments were administered through an online questionnaire system called CORF (www.corfstart.nl). The software packages SPSS 16.0 and Mplus 5.1 were used to analyze the data statistically.

Participants

Participants were recruited through a letter send by mail and, as a reminder, by email to the directive board of all primary schools in the Netherlands (nearly 7000 schools). Teachers from the upper grades (3-6) were asked to participate voluntarily. In order to stimulate participation, 10 annual season tickets for a science centre of choice were randomly assigned. Finally, 637 teachers participated, resulting in a response rate of approximately 9% (with the assumption that maximally 1 teacher per school would participate). The relatively low response rate was not unexpected and probably caused by primary school teachers' heavy work load and overwhelming amount of research projects that request teacher participation.

Only the data of teachers who fully completed the TTT (n=397) were included in the sample for the present study. This sample consisted of 39.2% male and 60.8% female primary school teachers in the Netherlands. Their mean age was 42.5 years (sd=11.9), their mean years of teaching experience 17.7 years (sd=12.1), and their mean years of technology teaching experience 4.4 years (sd=6.8). Most teachers (88.7%) in the sample taught in the upper grades (3-6) of primary education. The denomination of the schools, in which the teachers worked, was 41.7% Roman catholic, 21.6% protestant, 25.1% public (non-religious), and 11.6% other (e.g., reformed or Muslim). With regard to these variables, the sample is representative for the population of primary school teachers in the Netherlands. However, the sample might be biased in terms of motivation and attitude regarding technology education. Presumably, teachers who have a relative strong motivation for and positive attitude towards technology education are more likely to participate in this study.

Procedure

The procedure of data analysis started with removing empty and duplicate cases from the data file. Next, item responses on the TTT were checked by means of descriptive statistics. To distinguish between the three different answer categories (high, low, and no PCK), the answer alternatives that represent content knowledge and pedagogical knowledge were combined (i.e., recoded into a new variable). The TTT scores were calculated by counting the number of 'high PCK' responses (2 points) and 'low PCK' responses (1 point) dividing the total score by 36 (the maximum score) and multiplying it by 10 to obtain a score on a scale from 0 to 10. Subsequently, the TTT scores were tested for being normally distributed and difficulty values of the test items were calculated. Reliability of the TTT was analyzed in terms of internal consistency (Cronbach's alpha) and stability over time (test-retest reliability). To calculate test-retest reliability data of 31 teachers who completed the TTT in October/November 2008 and March 2009 was used. In order to examine the external aspect of construct validity (Messick 1995), the TTT scores were correlated with the Cito test scores (content knowledge) and STEBI scores (self-efficacy beliefs). Based on the reviewed literature, it was expected to find positive correlations with both of these scores. Furthermore, a t-test was run to check whether teachers who completed a refresher course on technology education performed indeed better on the TTT. Next, exploratory factor analysis (EFA) was performed to obtain clues for the latent factor models to be tested.

Based on scientific literature on PCK, three latent factor models were defined (see Table 2). Model 1 assumed a single underlying factor. That is, different

Table 2. Latent factor structures tested with confirmatory factor analysis

Model	Structure
Model 1	Model with one factor. Not distinguishing between different components of PCK. All items load on one and the same factor.
Model 2a	Model with two correlated factors. Distinguishing between PCK components 1 and 2+3. Items load on one of the factors.
Model 2b	Model with two uncorrelated factors. Distinguishing between PCK components 1 and 2+3. Items load on one of the factors.
Model 3a	Model with three correlated factors. Distinguishing between PCK components 1, 2, and 3. Items load on one of the factors.
Model 3b	Model with three uncorrelated factors. Distinguishing between PCK components 1, 2, and 3. Items load on one of the factors.

Table 3. Model fit statistics of CFA models

Model	$\chi 2$/df/p-value	CFI/TLI	RMSEA	SRMR
1	182.4/133/0.0029	0.533/0.462	0.031	0.048
2a	154.5/132/0.0876	0.787/0.753	0.021	0.045
2b	154.9/134/0.1047	0.803/0.775	0.020	0.045
3a	134.4/131/0.4022	0.968/0.963	0.008	0.041
3b	138.9/134/0.3683	0.954/0.947	0.010	0.042

components of PCK were not distinguished and all items were expected to load on one and the same factor. In model 2 two underlying factors were hypothesized. A distinction was supposed between knowledge component 1 and a combined component (2+3). It was theorized that regarding component 2 and 3 as one factor would result in a component that was rather similar to the second component of science PCK reported by Van Driel et al. (1998) (as described in section 'Pedagogical Content Knowledge' of this article). Component 1 was supposed to be a distinctive component and corresponded with the first component reported by the same authors. This model was tested with correlated (a) and uncorrelated (b) factors, which means that the model is applied less and more stringent, respectively. Model 3 assumed three underlying factors that distinguished between the three predefined knowledge components of technology PCK (also described in section 'Pedagogical Content Knowledge' of this article). Both a correlated (a) and uncorrelated (b) factor structure was tested. For each model a chi-square test was run and standard fit indices (Schermelleh-Engel et al. 2003), i.e., Comparative Fit Index (CFI) and Tucker Lewis Index (TLI), Root Mean Square Error of Approximation (RMSEA), and Standardized Root Mean Square Residual (SRMR), were computed.

RESULTS

Regarding the distribution of TTT scores, skewness was found to be slightly negative (-0.11, left skewed), but still within the range of a normal (Gaussian) distribution. The mean test score was 5.76 (sd=1.19) on a scale from 0 to 10. The difficulty values (i.e., proportion of correct items) were evenly distributed among the items, with a lowest value of 0.16 and a highest of 0.71 (10 items with difficulty value <0.50 and 8 items with difficulty value >0.50). Overall reliability of the test, calculated with Cronbach's alpha, was 0.34. However, in case of a heterogeneous construct, such as PCK, Cronbach's alpha is a strict lower bound to reliability and is a poor measure for consistency of the scale (Lucke 2005). Alternatively, test-retest reliability was calculated by correlating the test scores of both administrations (October/November 2008 and March 2009). Pearson's correlation coefficient and was found to be 0.622 ($p<0.01$; n=31).

Concerning the construct validity of the TTT, correlations with test scores on the Cito technology test and STEBI (PSTE scale) were calculated. The correlation coefficient between the TTT score and the Cito score was significant and positive, but small ($r=0.153$; $p<0.01$). The same applied for the correlation between the TTT score and the STEBI score ($r=0.208$; $p<0.01$). These small correlation coefficients might be caused by the low internal consistency of the TTT (i.e., attenuation). The correlations coefficients after correction for attenuation were respectively 0.401 (medium) and 0.239 (small). A t-test showed that teachers who completed a refresher course on technology education scored higher on average (mean=5.9; n=104) than teachers who did not (mean=5.7; n=293). However, the means were not statistically different (t=-1.59; df=395; p=0.11; mean difference=-0.22).

A principal factor analysis with varimax (orthogonal) rotation revealed three factors. These factors could be interpreted theoretically as the predefined knowledge components of PCK. Factor 1 was labeled as knowledge of pupils' general concept and misconceptions related to technology, factor 2 as knowledge of the nature and purpose of technology education, and factor 3 as knowledge of pedagogical approaches and teaching strategies for technology education. It was noted that factor 2 contained most of the easy items, which could be explained by the kind of knowledge this component contains. In other words, knowledge about the nature and purpose of technology education could be regarded as an 'easier' kind of knowledge than the other two components. The EFA gave no clues for any topic (content) or phase related factor structure.

To find out which factor structure underlies primary school teachers' PCK of technology education, the models in Table 2 were tested by use of confirmatory factor analysis (CFA). The fit for each model is presented in Table 3. The data did not support the models with one (model 1) or two factors (model 2a and 2b). The model with three correlated factors (3a) fitted the data best. With a non-significant p-value of the chi-square test, a CFI and TLI that were larger than 0.95, and a RMSEA and SRMR smaller than 0.05, the fit of this model was close. The factors could be denominated as independent, since the correlations between the factors were statistically non-significant and small (F1*F2:0.102; F1*F3:-0.006; F2*F3:0.294), though factor 2 and 3 clearly showed some correspondence.

Factor loadings of the items were investigated in order to (re)interpret the content of each factor (see Table 4). On the first factor items 4 and 14 loaded most strongly. Items 10 and 15 loaded most strongly on the second factor and item 7 on the third factor. Item 9 is associated with factor 1 and 2 at the same time. Three items (2, 6, and 13) showed non-significant factor loadings. Omitting item 13, which is the item with lowest factor loading, from the CFA caused a slight improvement of model fit. In addition to the factor loadings, the percentages of variance explained in each of the items are shown in Table 4. The percentages range between 0.2% (item 13) and 26.9% (item 11). The largest amount of variance was explained for item 10. The least amount was explained for item 13.

Reliability of the three factors was investigated by calculating internal consistency (Cronbach's alpha) and stability (test-retest reliability). For factor 1 an alpha of 0.39 was found (0.41 without item 2). For factor 2 alpha was 0.34 and for factor 3 alpha was 0.23 (0.27 without items 6 and 13). Because of the heterogeneous nature of PCK, internal consistency was not expected to be high.

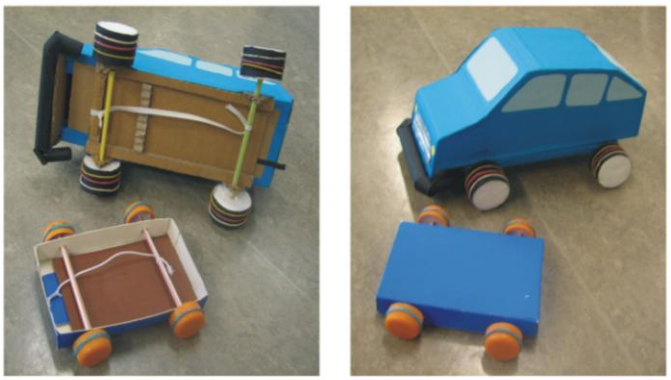
Table 4. Factor loadings (standardized) and percentages explained variance.

Factor	Item	Factor loading	Expl. var. (%)
1	1	0.182	3.3
	2	0.086 *n.s.*	0.7
	3	0.221	4.9
	4	0.466	21.7
	9	0.318	16.5
	12	0.210	4.4
	14	0.408	16.7
	18	0.282	8.0
2	9	0.222	16.5
	10	0.519	26.9
	15	0.340	11.5
	16	0.214	4.6
	17	0.185	3.4
3	5	0.273	7.5
	6	0.077 *n.s.*	0.6
	7	0.467	21.8
	8	0.244	6.0
	11	0.258	6.6
	13	0.042 *n.s.*	0.2

Alternatively, test-retest reliability was calculated by correlating the test scores on the three subscales (factors) separately. For factor 1 the Pearson correlation coefficient was 0.325 ($p<0.01$), for factor 2 0.516 ($p<0.01$), and for factor 3 0.373 ($p<0.01$). To recall, test-retest reliability for the overall test was 0.622 ($p<0.01$, $n=31$).

CONCLUSIONS

The reported study aimed at exploring teachers' PCK of technology education by analyzing the latent factor structure with use of CFA models. The CFA model with three factors (model 3a) showed the best fit with the data, which indicates that the knowledge components of technology PCK can be distinguished in three factors, as was expected from the reviewed literature. However, the factors have relatively low factor loadings and explain relatively small amounts of variance. That is, the factor structure is not prominently present and seems to be obscured by intervening elements. A possible explanation is that the items are aggregated, that is, consist of several intrinsic elements that interrelate to some extent, but not strongly. Alternatively, the items could contain extrinsic 'noise' (i.e., disturbing elements), such as interpretations difficulties related to complexity or text length of the items.



Two pupils together make a car out of cardboard (see pictures above), which can move due to a rotatable axle to which wheels made from bottle tops have been attached. The car can move forwards by winding up an elastic band attached to the axle and then letting go. The pupils test their car on a smooth table. However they are disappointed to discover that although the wheels rotate, the car scarcely moves forward. The pupils suspect that their car is too heavy but do not know a solution for this problem.

Which one of the following approaches can best be used to help these pupils?

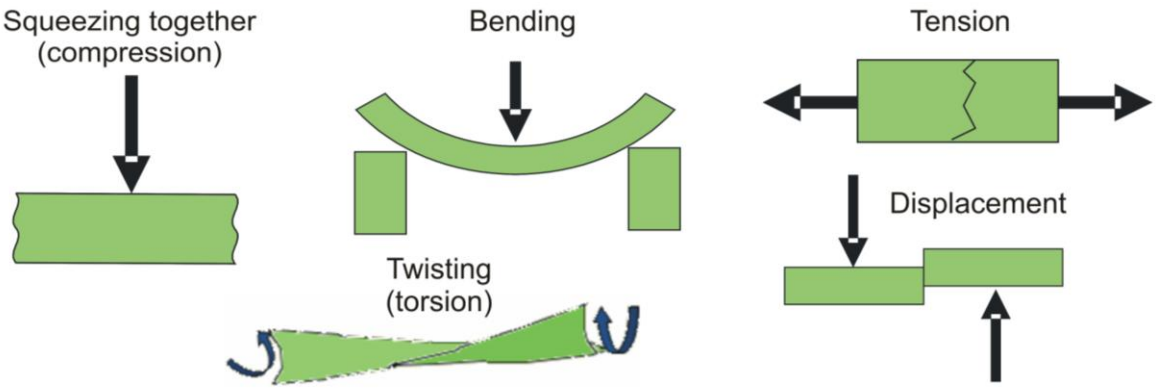
a. You join in with pupils' line of thought and from this perspective you try to help them discover the relationship between friction, drive and weight.
b. You draw the pupil's attention to the elastic band and the weight of the car and make sure that they continue searching for a solution.
c. You let the pupils compare their car with those of the other pupils so that they can reach a solution.
d. You explain to the pupils that two smooth surfaces easily move over each other due to the lack of friction. You advise them to attach elastic bands to the wheels to give these more grip.

Figure 1. Item 4 of the Teaching of Technology Test (a=high PCK, b=low PCK, c=content knowledge, d=pedagogical knowledge). Note: before administrating the test the sequence of answers was randomly determined.

Items with a high factor loading and which have a large amount of explained variance are good representatives of the scale. Regarding factor 1, item 4 (see Figure 1) and item 14 had relatively high factor loadings. Both items clearly handle with the way pupils experience the technological world around them and how education can change misconceptions into correct conceptions. Item 10 (see Figure 2) and item 15, which loaded high on factor 2, focus on two core characteristics of technology education, namely hands-on experiences and authentic problems. Factor 3 contains items that are related to pedagogical strategies. Item 7 (see Figure 3), which had the highest factor loading, deals with the important pedagogical strategy of asking learning questions that make pupils think critically. Item 9 (see Figure 4) loaded on both factor 1 and 2. This implies that these knowledge components were both needed to choose the best alternative (high PCK). Item 9 is about pupils' conception of fuses in electrical circuits and about how to avoid misconceptions concerning this topic (factor 1). At the same time, the item concerns the notion that technology education involves hands-on activities by nature (factor 2).

The items with a low, non-significant factor loading (items 2, 6, and 13) have a low predictive value for the scale. When taking a closer look at these items, it appears that they didn't succeed in being a good blend of the application of content and pedagogical knowledge in order to choose the best answer. Here, the balance turned over to the side of pedagogical knowledge. As Carlson (1990) and Kromrey and Renfrow (1991) noted, scoring high on PCK means that teachers have enough content knowledge to recognize the correct application of pedagogical strategies. The content knowledge part seems to be under-represented in these items.

We conclude that the presupposed factor structure of three knowledge components is confirmed. The first factor, labeled knowledge of pupils' general concept and misconceptions related to technology, can be best indicated as knowing how to adjust activities to pupils' experiences of the technological world around them and their (mis)conceptions of technological topics. The second factor, knowledge of the nature and purpose of technology education, is about knowing the core characteristics of technology education, i.e., hands-on experiences and authentic problem solving. The third factor, knowledge of pedagogical approaches and teaching strategies for technology education, has mainly to do with the art of asking questions that encourage pupils to think critically about the technological



As the teacher of grade 6 (11/12-year-olds) you want to teach the pupils how to allow for the forces that affect constructions and materials when they build something. The pupils are shown photos of chairs made from corrugated cardboard. They can see that corrugated cardboard constructions can be very strong. You want to explain the following terms: squeezing together (compression), tension, bending, twisting (torsion) and displacement. You show the pupils the diagram pictured above as a visual aid.

Which of the following methods is the most appropriate for explaining the terms?

a. The pupils design, make and test their own corrugated cardboard chair. Using the diagram an accurate analysis is made of what happens to the material and the construction when a load is placed on the chair and which forces play a role in this. Pupils are then given the task of making the chair even stronger still.
b. The pupils build a corrugated cardboard chair using an instruction sheet. They carefully analyse what happens to the material and the construction when a load is placed on the chair and which forces play a role in this. Then with the help of the diagram the pupils describe in their own words what happens if the construction or the material is not good.
c. You show the pupils a flimsy corrugated cardboard chair. You demonstrate that the chair sags and is not stable if you sit on it. Then you let the pupils make a strong corrugated cardboard chair. The diagram serves to support this task.
d. All of the pupils are given the diagram and several pieces of corrugated cardboard. You show the pupils how different ways of loading affect the corrugated cardboard. Using the diagram you explain exactly what happens. Then with the help of the diagram the pupils are given the task of assessing the various demonstration chairs for strength.

Figure 2. Item 10 of the Teaching of Technology Test (a=high PCK, b=low PCK, c=content knowledge, d=pedagogical knowledge). Note: before administrating the test the sequence of answers was randomly determined.

problem encountered. However, the factor structure turned out to be obscured by many other intrinsic elements of PCK. Therefore, we also conclude that PCK is a heterogeneous construct by nature. This implies that PCK consists of multiple intrinsic elements which can hardly be unraveled.

Furthermore, this study provides clues with regard to several aspects of construct validity of the TTT as described by Messick (1995) As expected from literature on PCK in science education (Van Driel et al. 1998; Park and Oliver 2008), the TTT scores correlated significantly with scores on tests that measure content knowledge (Cito) and self-efficacy (STEBI). However, the correlation coefficients were small, and for this reason the external aspect of construct validity could not be fully approved. Regarding the content aspect of construct validity, the experts who wrote and judged the items all agreed on the selection of items that formed the test and the predefined components of PCK were statistically confirmed by factor analysis. This implies that the TTT has sufficient content validity. Referring to the generalizability aspect across time, calculation of test-retest reliability showed that the test is satisfactory consistent over time. On the other hand, the internal consistency of the test (Cronbach's alpha) was found to be low, both for the three subscales as for the overall scale. The low alpha's could be legitimate because of the heterogeneous nature of the measured construct (Lucke 2005), but this needs further analysis. Overall it can be concluded that, although the results are promising, the TTT has no satisfactory psychometric properties yet and should be reconstructed before any practical application.

DISCUSSION

Several steps could be taken to improve the validity and reliability of the TTT. According to the Spearman-Brown prophecy formula, Cronbach's alpha will increase with lengthening of the test. However, when alpha is set at 0.60, the test needs to be lengthened 2.9 times. This implies that the test will contain at least 52 instead of 18 items, which is highly unpractical concerning the time needed to complete the test (approximately 2 hours and 10 minutes). An alternative way to improve the TTT might be to use a more structured approach to produce the items. Instead of


Two pupils have built a big wheel from K'nex (see the pictures above). The motor is attached to a gear that drives another gear (of equal size) on the axis of the big wheel. As a teacher you want to pose a question to encourage the pupils to formulate their own questions about cause-effect.

Which of the following questions can best be posed for this purpose?

a. "Can you change something on the big wheel so that it turns faster?"
b. "If you swap this small gear with a bigger gear what will happen to the turning speed?"
c. "Have you already changed something about the big wheel?"
d. "How often does the big wheel turn in one minute if you make the gears twice as large?"

Figure 3. Item 7 of the Teaching of Technology Test (a=high PCK, b=low PCK, c=content knowledge, d=pedagogical knowledge). Note: before administrating the test the sequence of answers was randomly determined.

There is a power cut at the school because the fuses have blown.

Which of the following technology activities can you best use in this situation to explain how fuses work?

a. The pupils make an electrical circuit with a voltage source, light bulbs, and wires. They investigate how a fuse works by placing a real fuse in the electrical circuit and letting this blow by adding more and more light bulbs to the circuit.
b. The pupils make an electrical circuit with a voltage source, a light bulb, and wires. How a fuse works is investigated by placing steel wool in the circuit and pointing out the sparks to the pupils.
c. You invite the electrician from the energy company who fixed the fuses to talk to the class about what was wrong and how he solved the problem.
d. You use a circuit diagram to explain how the fuse box in the school building works.

Figure 4. Item 9 of the Teaching of Technology Test (a=high PCK, b=low PCK, c=content knowledge, d=pedagogical knowledge). Note: before administrating the test the sequence of answers was randomly determined.

focusing on the item as a whole, that is, as representing one of the three PCK components, it could be beneficial to (better) isolate the PCK sub-elements in single items. In the present version of the TTT items may simply contain too many sub-elements of PCK, even sub-elements that belong to different PCK components. Moreover, one could consider including only one topic (e.g., electricity) and one phase (e.g., preparation) in the test in order to reduce the amount of variation across items. However, because heterogeneity is an inherent aspect of PCK, complete homogeneity of the sub-scales (factors) is not what should be strived for. It should rather be attempted to find an optimal balance between homogeneity and validity of the instrument.

In order to improve the external aspect of construct validity of the test, the TTT scores, which focus on the cognitive aspect of PCK, could be related to results from qualitative methods, which mainly measure the reasoning and behavioral aspect of PCK. It is expected that the TTT scores can predict teaching behavior and reasoning regarding PCK correctly. That is, a high score on the TTT is expected to relate positively with teaching behavior and reasoning that shows high amounts of PCK. Moreover, the substantive aspect of construct validity of the TTT could be verified by having the respondents think aloud while answering the test items.

Although many things could (and should) still be done to improve its validity, a multiple choice test, such as the TTT, has clear-cut advantages compared to other approaches of measuring PCK, such as multi method evaluations. First of all, collecting data with a multiple choice test is far more time and labor efficient, which also accounts for analysis of the data. Time and labor efficiency opens doors for data collection with large samples, which, in turn, makes generalization of the results legitimate. Second, psychometric quality indicators of the measurement are relatively easy to obtain and are more objective than non-statistical

indicators of quality. Besides, qualitative methods to measure PCK have to deal with the same heterogeneous nature of PCK, but this problem is obscured by the absence of psychometric indices. As Abell (2008) concluded, it is time to shift from descriptive, small-scale studies to explanative, large-scale studies to give a new impulse to research on PCK in science education. Measurement of PCK with a multiple choice test enables this kind of research.

On the whole, we consider further research on PCK in science and technology education valuable. Approaching the concept of PCK from different perspectives, e.g., investigating PCK with use of innovative methodologies will provide a more comprehensive picture of this important domain of teacher knowledge. More scientific knowledge on the concept of PCK could support specific professionalization of teachers and, consequently, contribute to the quality of science and technology education.

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Note

The Teaching of Technology Test is available on request for scientific purposes only. Please contact the author by e-mail: e.rohaan@fontys.nl

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